Alpha diversity of lowland fynbos herbs at various levels of infestation by alien annuals

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Alien annual herbs are presently invading the fynbos vegetation. Six study sites were surveyed, five of the sites are in lowland fynbos and one is in mountain fynbos. The alpha diversity of indigenous, summer deciduous herbs was recorded on 1-m^2 plots, along transects through areas where alien annuals occurred at various levels of infestation. There is a clear negative association between the density of alien annuals and the density and number of species of indigenous annuals and geophytes. This study documents the extent to which these alien species are able to replace the indigenous species and the consequent threat they pose to the survival of many endemic fynbos species.

Uitheemse eenjarige kruidgewasse dring tans die fynbosplantegroei binne. Opnames is in ses studie-areas gedoen, vyf is geleë in kusfynbos en een in bergfynbos. Transekte is uitgelê deur areas waar die uitheemse eenjarige kruide in verskillende vlakke van digthede voorgekom het en die alpha diversiteit van die inheemse, somerrustende kruide was aangeteken vir 1-m^2 persele. Daar is 'n duidelike negatiewe assosiasie tussen die digtheid van die uitheemse eenjarige kruide en digtheid van, asook aantal soorte van inheemse eenjarige kruide en geofiete. Hierdie studie dui aan in watter mate die uitheemse eenjarige kruidgewasse die inheemse soorte kan verdring en die gevaar wat dit vir die oorlewing van baie van die endemiese fynbos-soorte inhou.

Keywords: Alien invasion, annuals, conservation, geophytes, therophytes

Introduction

The herb element of the Cape flora is unusual in having a high proportion of geophytic species, but relatively few annual species (Goldblatt 1978). Almost 15% of the flora consists of monocotyledonous geophytes, but only 6,4% are annuals (Bond & Goldblatt 1984).

Most of the fynbos geophytes and annuals are summer dormant. They germinate or sprout in autumn and complete their life cycle by late spring or early summer. Geophytes, in particular, are known to respond well to removal of the shrub layer by either burning or mechanical clearing (Martin 1966; Waher 1974). The indigenous annuals seem to follow a similar pattern in being more abundant in open environments. The geophyte and annual elements in the Cape flora have largely been neglected in recent ecological studies, which have concentrated on the perennial evergreen elements. The biology of the deciduous element is therefore poorly known and understood.

Until recently, alien annuals have been regarded as invasives posing only a minor potential threat to the Cape flora (Macdonald & Jarman 1984), even though other regions with mediterranean climates have been severely invaded by alien annual grasses (Mooney *et al.* 1986; Rossiter 1966). In a more recent study Macdonald *et al.* (1987) found 29 exotic alien species in the Cape of Good Hope Nature Reserve, most of which were restricted to intensely disturbed areas and very open natural vegetation. In lowland fynbos on the Cape Flats, Campbell *et al.* (1980) found considerably less indigenous geophytes and annuals in communities that had been heavily invaded by alien annuals. It therefore seems possible that these alien annuals might be able to invade open areas and compete with fynbos annuals and geophytes, as was found by Bridgewater & Backshall (1981) in the Western Australian flora. They observed a reduction in alpha diversity with an increase in alien species where gaps, which were created by an increase in fire frequency and nutrient-rich dust, were filled by adventive therophytes. Even in their natural environment, an increase in dominance by grasses can lead to a reduction in local species diversity. This was recently shown by Bobbink & Willems (1987) to be the case in the species-rich chalk grasslands of the Netherlands, where a perennial grass *Brachypodium pinnatum* (L.) Beauv. increased in dominance due to additional nutrient supply by means of air pollution.

In this study I investigated the effect of various degrees of infestation by alien annuals on the abundance of indigenous annual and geophyte species. I concentrated on lowland fynbos, since indigenous annuals and geophytes are particularly common in this vegetation type. Furthermore, infestations of alien annuals seem to be more common in the lowland fynbos than in mountain fynbos.

Study sites

Six study sites were selected. Five of these were in lowland fynbos and one in mountain fynbos. The study sites were selected using the following criteria:

1. No perennial exotic species, such as *Acacia saligna*, present in the immediate vicinity.
2. No signs of mechanical soil disturbance.
3. No grazing by domestic stock during the last growing season.
4. Variable degrees of infestation by alien annuals within the site.
5. Presence of large numbers of indigenous geophytes and annuals.

The selected sites are listed below and vegetation types follow Moll *et al.* 1984 and nomenclature follows Bond & Goldblatt 1984.

Bredasdorp (site grid reference 34°38′25″ 20°12′12″)

A mosaic of Limestone Fynbos and South Coast Renosterveld at 40 m altitude. Prominent shrubs are *Leucadendron muirii, Nylandtia spinosa, Rhus* spp. and *Elytropappus rhinocerotis*.

The area was burnt approximately 4 years prior to sampling and heavily grazed in the subsequent 3 years. However, no grazing has taken place during the last growth season (Allison pers. comm.). This treatment resulted in an almost total removal of the shrub element. Degrees of invasion by the alien annuals varied throughout the area.

Gordons Bay (site grid reference 34°08′30″ 18°51′10″)

West Coast Renosterveld at 30 m altitude, with *Elytropappus rhinocerotis, Diosma hirsuta* and *Themeda triandra* prominent in the area.

Part of the site was mowed with a brush cutter and invasion by the alien annuals was largely limited to this area. The transect included both mowed and unmowed areas.

Cape Flats (site grid reference 33°51′00″ 18°32′25″)

Sand Plain Fynbos at 50 m altitude, with *Chrysanthemoides monilifera, Metalasia muricata* and *Stenotaphrum secundatum* as prominent species. Alien annual invasion occurred throughout the area, but was especially abundant in areas with little indigenous shrub cover. Soil disturbance due to mole rat activity occurred in the area.

Darling (site grid reference 33°24′30″ 18°25′00″)

West Coast Renosterveld on decomposed granite at 120 m altitude. *Putterlickia pyracantha, Salvia africana-lutea, Eriocephalus africanus* and *Elytropappus rhinocerotis* were prominent shrubs in the area.

Large areas had been mechanically cleared of shrubs and phosphate fertilizer had been applied to improve the value of the land for grazing. Alien annuals occurred throughout the area at various densities. Grazing by domestic stock was prevented from autumn to late spring to allow for a good show of spring flowers (Duckitt pers. comm.).

Tygerberg (site grid reference 33°53′10″ 18°36′20″)

West Coast Renosterveld on shales at 180 m altitude. *Elytropappus rhinocerotis, Athanasia dentata* and *Erharta calycina* were prominent at this site. The area is adjacent to a suburb and is mown annually to prevent the vegetation from becoming too tall. Invasion by alien annuals occurred through the area at varied intensities.

Karweiderskraal (Hermanus) (site grid reference 34° 21′20″ 19°12′12″)

Mesic Mountain Fynbos at 190 m altitude. *Protea repens, Restio triticeus* and *Leucadendron salignum* were prominent in the area. The area was burnt approximately 2 years prior to sampling and grazed severely the following year. No grazing seemed to have taken place during the last growing season. Some fertilizer (mainly nitrogen and phosphates) had washed down from adjacent cultivated land and the alien annuals were particularly prominent in drainage lines (Wilson pers. comm.).

Methods

At each site 1-m^2 (1-m × 1-m) plots were laid out at 5-m intervals along a transect. The alien annuals occurred in patches of various sizes (up to 300 m^2), usually at very high densities in the center of the patch and gradually becoming sparser towards the edges. The transects were chosen to run through several of these patches, so as to sample the alpha diversity and number of individuals of the indigenous herbs at all the levels of alien annual infestation. At Bredasdorp 14 plots were sampled, at Gordons Bay 12 plots, at the Cape Flats 16 plots, at Darling 17 plots, at Tygerberg 17 plots and at Karweiderskraal 11 plots.

Cover was estimated for each species on every plot. In addition, all the geophytes in the plot were counted and the total number of species was recorded. The total cover value per plot of alien and indigenous annuals was calculated by adding together all the individual percentages. The total percentage cover per plot may therefore exceed 100% where canopies of different species overlapped.

The sites were surveyed on two occasions, 19 plots were laid out during the second week of September 1986 and another 68 additional plots during the first week of October 1986. The Cape Flats, Darling and Tygerberg sites were visited on both occasions, as time was limited during the first survey and only a few plots were sampled. The data from the two periods were combined as no obvious changes took place during the intervening 3 weeks.

For each site the correlation coefficient was calculated to test the null hypotheses that there is no correlation between alien annual percentage cover and alpha diversity of the indigenous annuals and geophytes. Logarithmic transformations of the Y variable (number of indigenous species) were done to normalize the data. As a negative correlation was found between alien annual cover and alpha diversity of indigenous annuals and geophytes for all the sites, the data from all the 87 plots were combined and analysed further.

The null hypothesis, that the frequency of the plots with high values, both of number of individuals or species or the cover of indigenous plants, is independent of infestation level, was then tested. The Chi-squared test was used to compare the distribution of plots with high versus low values, at high (> 50%) and low (< 50%) levels of infestation by alien annuals. To divide the plots between those with high versus low values, the highest cut-off point was selected, at which the derived expected values are more than five plots. This was done to ensure that the Chi-squared tests are valid. These cut off points were as follows: 10 species for the total number of indigenous species; > 20% cover for percentage cover of indigenous annuals; > 4 species for number of indigenous annual species; > 70 plants for number of geophyte plants and > 6 species for number of geophyte species.

Results and Discussion

A list of the alien annual species, as well as the number of plots that were sampled at high and low infestation levels at the different study sites, are given in Appendix 1. The null hypothesis for both the within-site and combined plots was rejected in all cases, either at 1, 2 or 5% confidence levels. The results are presented in Tables 1 and 2. There is a negative association between alien annuals and indigenous annual and geophyte species. Figure 1 shows the total number of indigenous deciduous herb species per plot at various levels of alien annual infestations. Low numbers of the indigenous species are especially evident when the cover of alien annuals exceeds 80%.

Table 1 Value and significance of correlation coefficient between alien annual cover and alpha diversity of indigenous summer deciduous herbs

Site	r	df	
Bredasdorp	–0,871	12	< 0,001
Karweiderskraal	–0,969	9	< 0,001
Gordons Bay	–0,875	10	< 0,001
Cape Flats	–0,737	14	< 0,002
Tygerberg	–0,832	15	< 0,001
Darling	–0,605	15	< 0,01

The cover of indigenous annuals and density of geophytes, as well as the number of species in both these categories, separately and combined, decrease with increasing levels of exotic cover (Figures 2–5). Alien cover values of less than 10% were usually found along the perimeters of the patches of alien annuals indicating either pristine conditions or very recent invasions where the aliens are spreading along the edges of the patches of alien annuals (Vlok pers. obs.).

Table 2 Significance of Chi-squared test on differences between values at high (> 50%) and low (< 50%) levels of infestation by exotic annuals. Values from all 87 plots were used

	Chi-squared value	*df*	*P*
Total no. indigenous annual and geophytic species	9,602	1	< 0,005
Percentage cover of indigenous annuals	11,223	1	< 0,005
No. indigenous annual species	12,184	1	< 0,005
No. indigenous geophyte plants	5,442	1	< 0,025
No. indigenous geophytic species	13,779	1	< 0,005

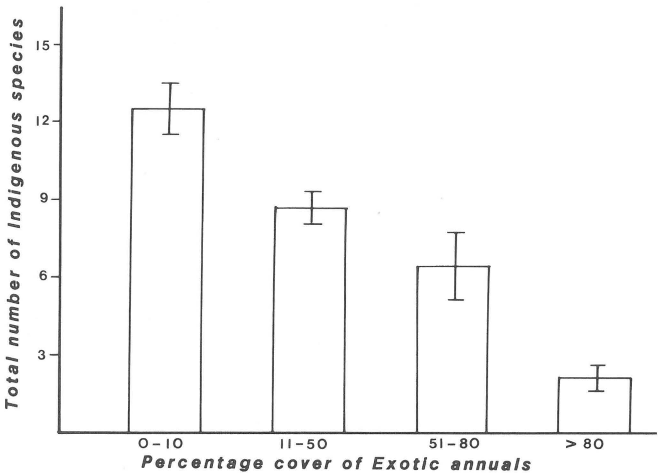

Figure 1 The number of indigenous geophytic and annual species per 1 m^2 recorded at various levels of infestation by alien annuals. (The mean values and *S.E.* of the plots in each infestation category are indicated. The number of plots in each category are as follows: 0–10%, *n*=24; 11–50%, *n*=28; 51–80%, *n*=13 and > 80%, *n*=22).

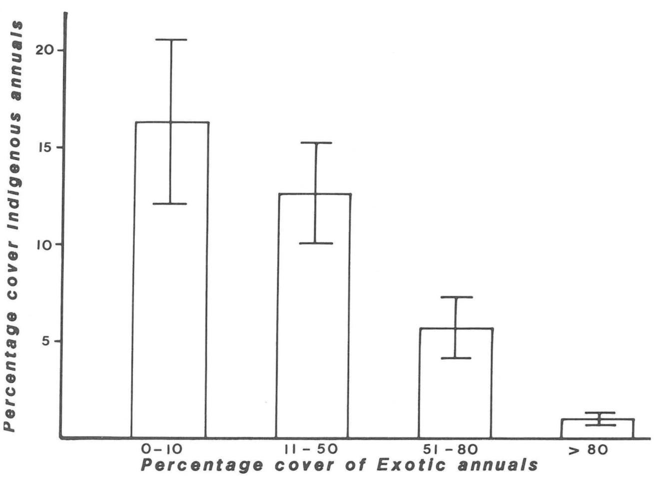

Figure 2 The percentage cover of indigenous annuals per 1 m^2 recorded at various levels of infestation by alien annuals. (The mean values and *S.E.* of the plots in each infestation category are indicated. The number of plots in each category is as follows: 0–10%, *n*=24; 11–50%, *n*=28; 51–80%, *n*=13 and > 80%, *n*=22).

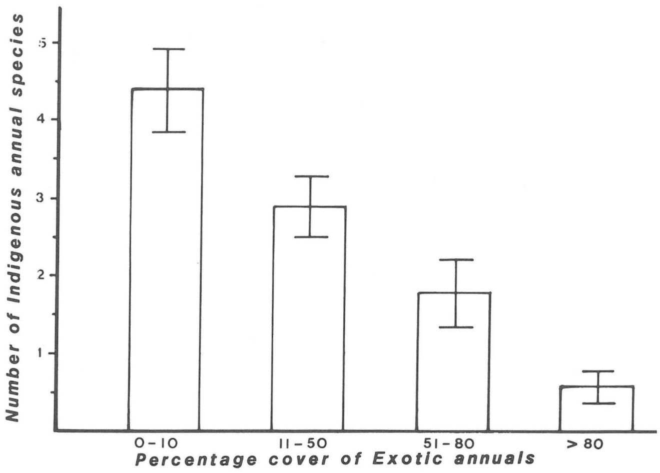

Figure 3 The number of indigenous annual species per 1 m^2 recorded at various levels of infestation by alien annuals. (The mean values and *S.E.* of all 87 plots are indicated. The number of plots in each category is as follows: 0–10%, *n*=24; 11–50%, *n*=28; 51–80%, *n*=13 and > 80%, *n*=22).

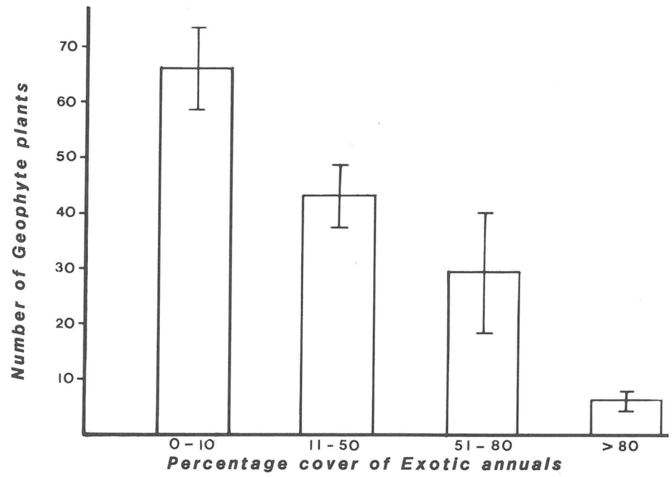

Figure 4 The number of indigenous geophyte plants per 1 m^2 recorded at various levels of infestation by alien annuals. (The mean values and *S.E.* of all 87 plots are indicated. The number of plots in each category is as follows: 0–10%, *n*=24; 11–50%, *n*=28; 51–80%, *n*=13 and > 80%, *n*=22).

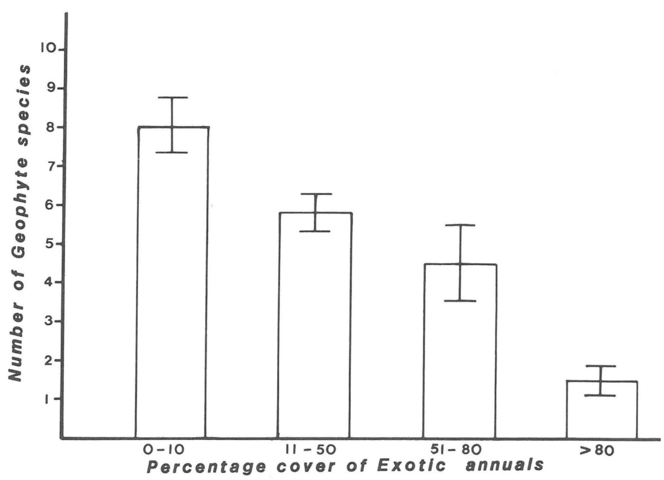

Figure 5 The number of indigenous geophytic species per 1 m^2 recorded at various levels of infestation by alien annuals. (The mean values and *S.E.* of all 87 plots are indicated. The number of plots in each category is as follows: 0–10%, *n*=24; 11–50%, *n*=28; 51–80%, *n*=13 and > 80%, *n*=22).

Table 3 Mean alpha-diversity of indigenous annual and geophyte species at the different study sites. (Data were extracted from the 1-m^2 quadrats where alien cover was < 10%)

Site	Mean alpha-diversity	Number of plots	*S.E.*
Bredasdorp	18,0 species m^{-2}	3	2,7
Karweiderskraal	11,0 species m^{-2}	3	0,6
Gordon's Bay	13,3 species m^{-2}	4	1,3
Cape Flats	9,5 species m^{-2}	6	1,5
Tygerberg	10,9 species m^{-2}	7	1,6
Darling	18,0 species m^{-2}	4	2,6

High or low values of indigenous species can be found under such conditions, depending on the species richness of the area (see Table 3). At infestation levels of more than 10% the average number of indigenous plants and/or species decrease gradually but steadily. Alien cover values of more than 80%, which are usually situated in the centre of the patches of alien annuals, indicate sites where the exotic annuals are apparently well established and often include several mono- and dicotolydenous alien species. Very few indigenous annuals persist under such conditions, the persistant species often being *Arctotheca calendula* and *Dimorphoteca pluvialis*. The taller geophytic species seem to be more resistant to invasion by the exotic annuals. Those species that are able to attain a height of 30 cm and more are the only geophyte species that are able to remain at more than 80% infestation levels. These plants are presumably able to compete successfully for sunlight.

No data were collected on the occurrence of alien annuals in relation to disturbance level of the natural fynbos vegetation. The alien annuals tended to be only at sites where the natural shrub element was very sparse or absent. (Vlok pers. obs.). This was also observed by Macdonald *et al.* (1987) in the Cape of Good Hope Nature Reserve, where the alien annuals were restricted to severely disturbed sites. In California Hobbs & Mooney (1986) found that the abundance of the alien annuals (many of which species are the same species that were found in this study) declined greatly after a closed shrub canopy was formed. Little seed of these alien annuals was dispersed into the shrub stands or stored in the soil under the shrubs. Exclosures suggested that herbivory by small mammals in the closed shrub stands may be important in reducing the abundance of the alien annuals in the closed shrub stands (Hobbs & Mooney 1986).

Conclusion

Alien annuals are able to establish successfully in lowland fynbos environments. They appear to pose a severe threat to the indigenous flora. Several rare and highly localized species, such as *Cotula duckittiae, Nemesia strumosa, Babiana rubrocyanea, Geissorhiza monantha, G. radians, Ixia maculata, I. versicolor* and *Romulea eximia* were found at the study sites (cf. Hall & Veldhuis 1985). These highly endemic annuals and geophytes might become extinct in the wild if the alien annuals continue to spread and increase in abundance at the localities of these indigenous species. Research is needed to establish how to prevent such areas from invasion by the alien annuals, as well as how to control those that have already established in such areas.

Many of the invasive annuals, especially the Poaceae, are used for vegetation reclaimation work on road-sides. It is also general practice to fertilize such areas to improve their growth rates. Research is needed to establish to what extent these alien annuals are able to spread into undisturbed natural vegetation.

Although no data were collected on the effect of the alien annuals on establishment of seedlings of long-lived shrubs, no such seedlings were found on the 48 × 1-m^2 quadrats where the aliens were well established. It is possible that the alien annuals are able to suppress the re-establishment of perennial indigenous shrubs. Further research is also needed to clarify this aspect, especially since I have observed similar invasions under perennial shrubs in the Little Karoo (Oudtshoorn District) and on the Roggeveld plateaux (Sutherland District).

In California, replacement of the native flora by annual European weeds has been so thorough that a new vegetation type, 'valley grassland', has been created. So complete is the invasion that the nature of the original vegetation is unknown (Heady 1977). This study suggests that a similar process is beginning in an area rich in endemic elements of the Cape flora.

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Appendix 1 List of alien annual species encountered in plots and number of 1-m^2 quadrats sampled at high and low infestation levels

	Bredasdorp		Gordon's Bay		Cape Flats		Darling		Tygerberg		Karweiders-kraal	
Alien infestation level	<50%	>50%	<50%	>50%	<50%	>50%	<50%	>50%	<50%	>50%	<50%	>50%
No. of plots sampled	8	6	8	4	9	7	6	11	9	8	8	3
Dicotyledonous species												
Anagallis arvensis L.	*		*		*		*		*		*	
Carduus pycnocephalus L.	*								*		*	
Echium lycopis L.	*		*									
Erodium moschatum L'Hér	*		*		*				*			
Lotus angustissimus L.	*		*				*		*			
Medicago hispida Gaertn	*		*				*		*			
Melilotus indica (L.) All	*						*					
Plantago major L.	*				*				*		*	
Raphanus raphanistrum L.	*								*			
Reseda lutea L.	*		*				*		*			
Taraxacum spp.	*				*		*		*		*	
Trifolium angustifolium L.	*		*				*					
Trifolium arvense L.					*				*		*	
Vicia atropurpurea Desf.			*		*		*		*			
Monocotyledonous species												
Avena fatua L.	*		*				*		*			
Avena sativa L.	*		*		*		*		*		*	
Brachypodium distachyon (L.) Beauv.	*						*		*			
Briza minor L.	*		*		*				*		*	
Briza maxima L.			*		*				*		*	
Exotic annuals												
Bromus diandrus Rothi	*				*		*		*			
Hordeum murinum ssp. *glaucum* (Stend.) Tzvel	*		*				*					
ssp. *gussoneanum* (Parl.) Theil							*					
Lolium perenne L.	*		*		*						*	
Lolium rigidum L.	*				*		*		*			
Lolium temulentum L.			*		*		*		*			
Phalaris canariensis L.	*				*		*		*		*	
Vulpia bromoides (L.) Gray	*						*					